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A SIMPLE PORTABLE SONOMICROMETER

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FOREWORD

The sonomicrometer described in this report was constructed to fulfill a need for continuous registration of cardiac dimensions in conscious dogs exposed to acceleration stress. The instrument was developed in the Biodynamics Branch, USAF School of Aerospace Medicine, between March 1966 and July 1966. The work was accomplished under task No. 793003 and was supported in part by National Aeronautics and Space Agency contract No. T-37761-G. The paper was submitted for publication on 24 August 1966.

All experiments were conducted according to the "Principles of Laboratory Animal Care" of the National Society for Medical Research.

The authors extend their appreciation to Dr. V. S. Bishop, Roy Turner, and Master Sergeant Ben Wiggins for their assistance and suggestions.

This report has been reviewed and is approved.

James B Nuttall

JAMES B. NUTTALL
Colonel, USAF, MC
Commander

ABSTRACT

The design and construction of a relatively simple and inexpensive ultrasonic dimension gage (sonomicrometer) are described in detail. Two piezoelectric crystals are installed surgically across the organ to be studied, and the transit time for a burst of ultrasound to pass from one crystal to the other is measured. The device is easily calibrated when sound velocity in the medium is known. By use of integrated circuits throughout, it may be duplicated for less than $55. Possible applications other than continuous measurements of organ size are discussed.

A SIMPLE PORTABLE SONOMICROMETER

I. INTRODUCTION

Continuous, dynamic, direct measurements of organ dimensions in man and animals are necessary in order to understand changes in organic function. In particular, reactions of the heart to various stresses can be detected by measurements of ventricular diameter (1).

Among the technics that have been suggested as means of obtaining organ dimensions in the conscious animal, Peterson (2) lists five:

1. Resistance strain gages.
2. Inductance strain gages.
3. Impedance plethysmographs.
4. Optical and roentgenographic technics.
5. Sonic (i.e., ultrasonic) methods.

The latter offer several advantages. They are inherently calibrated since transit time is directly proportional to distance when velocity is known. Drift is entirely an electronic problem because the sensors do not change properties. The transducer is light and the two halves are not physically linked, thus allowing free motion of the organ under measurement.

Instead of using the arrival time of an ultrasonic echo, as is done in conventional sonar, Baker (3) suggested that transit time of sound between two piezoelectric crystals mounted on either side of an organ could be used to indicate changes in the distance between the crystals. Using this principle, we developed a "sonomicrometer," which eliminates the major objection to using sonic technics—i.e., the need for complex, cumbersome circuitry to process the information. In order to obtain either telemetered or hard-wire-transmitted measurements from an animal under stress, it was also desirable to have a lightweight, battery-operated instrument.

II. DESIGN

Figure 1 is a block diagram of the designed instrument and shows the technic of information processing used. A pulse from an avalanche mode oscillator ("pinger") excites the transmitting crystal and also sets a monostable multivibrator. The trailing edge of the monostable sets a bistable multivibrator about 3 to 4 μsec. after the initial pulse. Ultrasonic energy in the form of a burst of 5 mHz sound waves passes through the organ and is detected by the receiving crystal. The received signal is then used to reset the bistable multivibrator, completing one timing cycle. The bistable output is filtered through a conventional R-C network for recording.

Tracing one complete timing cycle yields a clearer picture of the function of each element. Each cycle begins with the ultrafast pulse (less than 10^{-8} seconds rise time) from the blocking oscillator. Ringing appears on this pulse because it drives the resonant piezoelectric element. Although minimized by the very low output impedance of the pulse generator, some ringing is capacitatively coupled and appears immediately at the receiver. If the bistable multivibrator were "set" by the original oscillator pulse, it would be quickly "reset" by this capacitatively coupled signal. Baker (3) suggested that the receiver be gated "off" during this early period in order to avoid the problem, but a simpler solution was found by delaying the "set" pulse by means of a monostable multivibrator whose width was greater than this capacitatively coupled pulse. Moreover, as will be seen below, monostable width could be varied for zero suppression when pulsatile changes in distance were to be recorded.

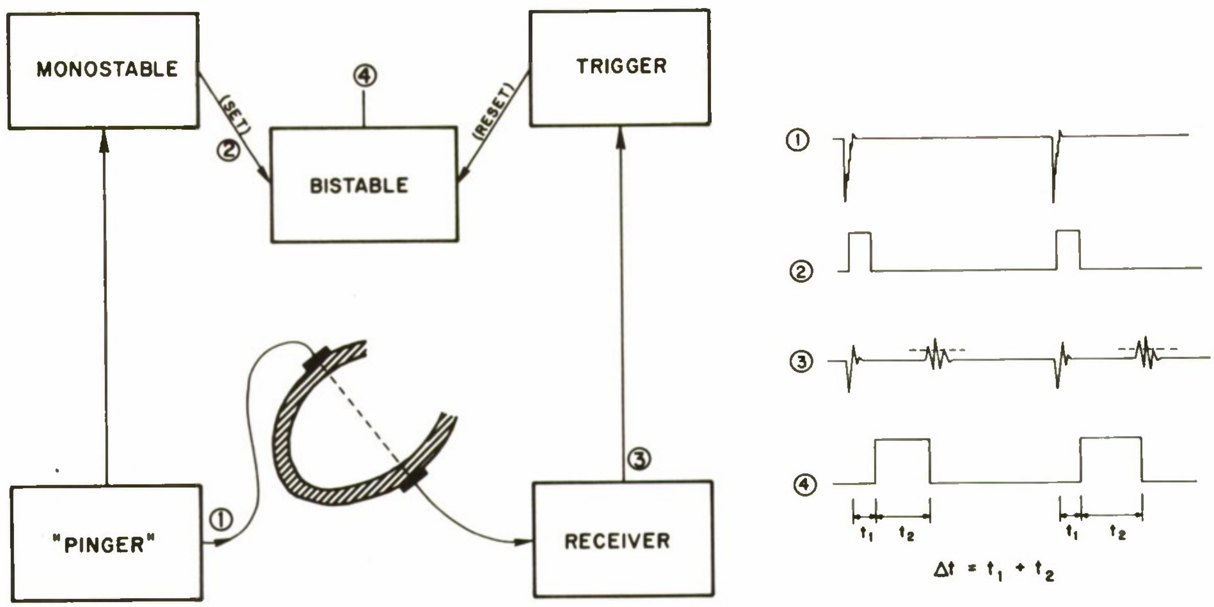

FIGURE 1

Block diagram with waveforms illustrating the output of each stage: (1) shows the "pinger" pulse, which drives the transmitting crystal; (2) is the monostable multivibrator output (trailing edge "sets" the bistable); (3) is the receiver output, showing "pinger" pulse feedthrough and received packet, which "resets" the bistable; (4) is the bistable multivibrator output (t_2 varies with transit time).

Low-frequency components at approximately 0.5 mHz, apparently the result of oscillations other than in the thickness mode, were eliminated by a high-pass L-C filter between the receiver and the Schmitt trigger. The trigger detects the time when the receiver output rises above electronic noise in the system, forming a positive pulse which resets the bistable multivibrator. Ordinarily, this is adjusted to occur during the leading edge of the first or second positive half-cycle, whichever is most stable. With this, the bistable multivibrator is reset, and thus a timing cycle is completed.

Bistable output is a rectangular pulse whose duration is equal to the acoustic delay between transmitted and received pulse less the electronic delay of the monostable multivibrator. Since pulse repetition rate is constant, the distance information appears as duty cycle modulation, and may be recovered by a simple R-C filter. A repetition rate of 5,000 measurements per second was selected in order to maintain good sensitivity and reduce crosstalk with other ultrasonic sensors. Increasing the monostable delay reduces the pulse width by a fixed amount, thus allowing easier inspection of pulsatile changes in organ size.

Figure 2 (*A*, *B*, *C*, *D*) is the schematic for the finished design. With the exception of the transmitter ("pinger"), all stages use integrated circuits available at a cost of $4 to $15 each. Cost for all parts for the entire circuit is less than $55, and may soon be even lower as the cost of integrated circuits continues to fall. A competent technician should be able to duplicate this instrument within a relatively brief time since no special construction technics appear necessary other than the usual precautions in high-frequency design: short leads with careful lead dress, decoupling between stages, etc.

III. CONSTRUCTION

As pictured in figure 3, the sonomicrometer was constructed in separate stages with each stage on a separate copper-clad board. The

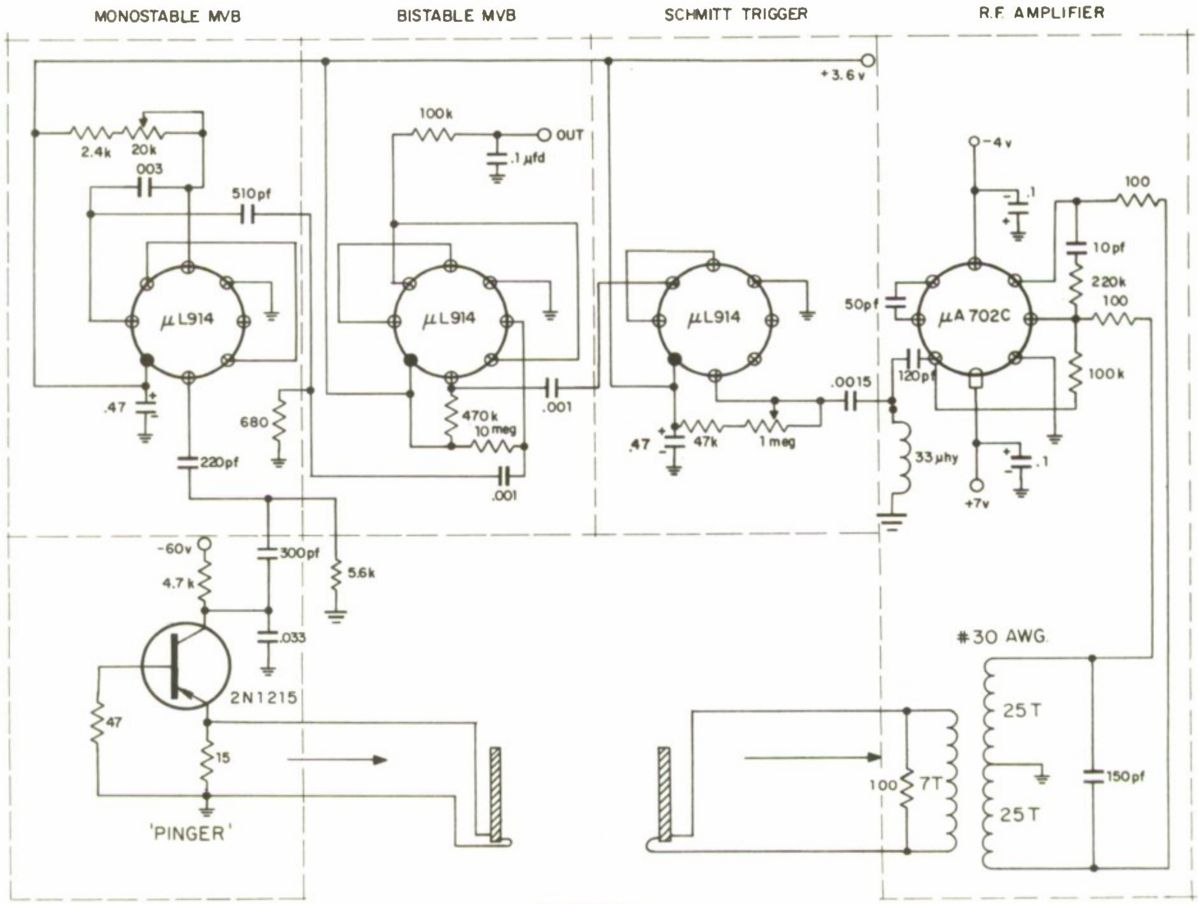

FIGURE 2A

Schematic of complete sonomicrometer. All resistors are ¼ watt; all capacitors are listed in microfarads unless otherwise stated.

copper coating was left intact except around the isolated interconnection pins. All grounds were carried directly to the intact copper coating. Tied together by two ⅛-inch brass rods with threaded ends, the assembly was placed inside a brass box (fig. 4). Connections were included for attaching crystals, supplying power, and testing the output from each stage. A lid (not shown) completed the construction.

Piezoelectric transducers were constructed by use of a ceramic material resonant at approximately 5 mHz in its thickness mode. Cut to 2 to 5 mm. round, the crystals were placed in specially cast holders as shown in figure 5. The crystal holders were cast from small, hollow, nontoxic polystyrene beads in a brass mold heated to 150° C. for 10 minutes; they have about the same consistency as hot-drink cups. A hole drilled from one end through the holder toward its center allowed for the passage of a pair of wires to connect to the crystal faces. Several additional holes were drilled around its circumference for suture placement. A spherical (⅛-inch to ¼-inch radius of curvature) polyester lens was glued to the outer face of each crystal to reduce directivity and broaden the ultrasonic beam.

Wires were soldered to the crystal faces with a low temperature solder, melting at approximately 100° C., and a soldering iron just warm enough to melt it. First, a small section of the surface coating was scraped from the crystal, thus exposing the metal plating underneath. A tiny drop of special flux supplied with the solder was applied, and a very small dot of solder was then carried on the tip of the

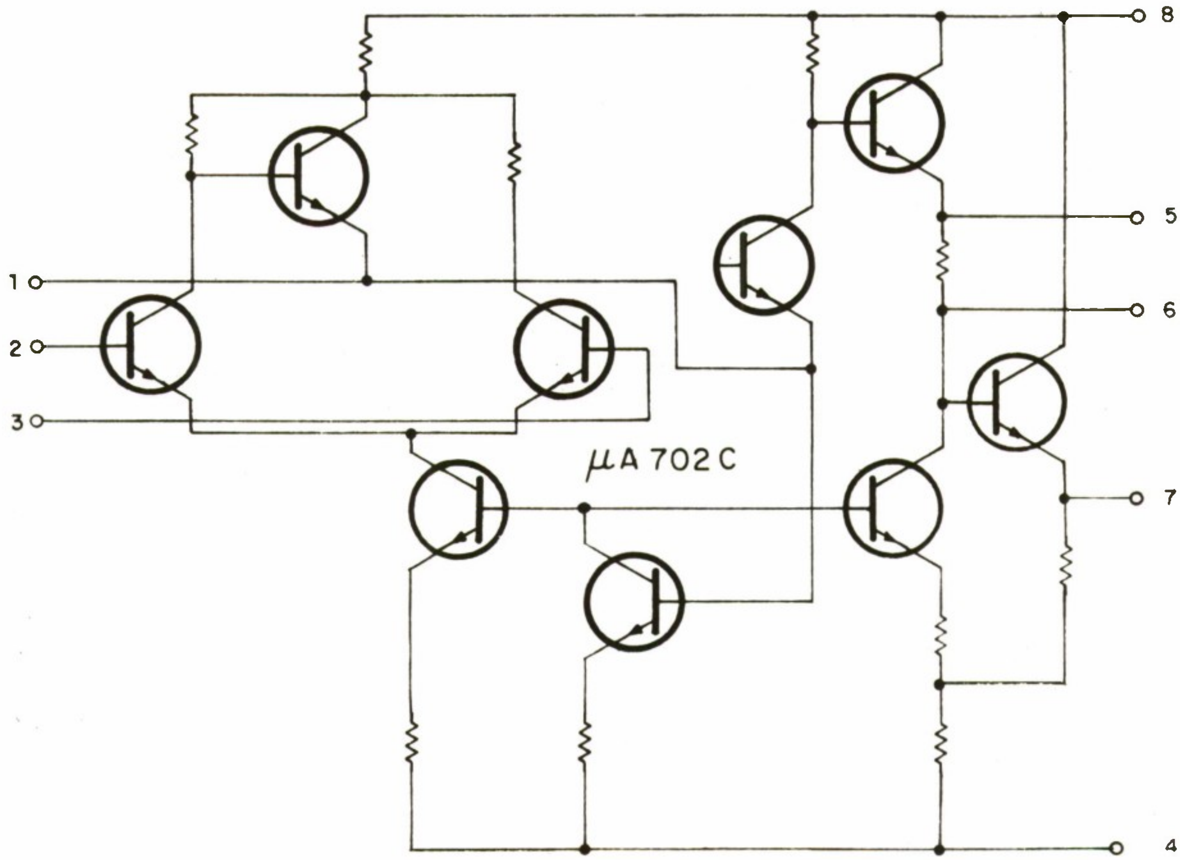

FIGURE 2B

Internal components and lead connections for Fairchild μA702C integrated circuit used as radio frequency amplifier.

iron to the prepared spot. A quick touch deposited the solder dot on the prepared surface, and a pre-tinned wire was laid over this spot and, in turn, fused to it with the iron. With some practice, the operator learned to apply a relatively small amount of heat to the crystal, thereby reducing the chance of thermal damage to the piezoelectric material.

Instrument characteristics

A jig was constructed to hold two crystal transducers at distances which could be varied with a micrometer. The entire assembly was placed under water at room temperature, and output of the sonomicrometer was plotted as a function of distance between the crystals. Figure 6 illustrates that output varied linearly with crystal spacing, and that overall sensitivity was approximately 6.7 mv./mm. change in spacing. After batteries had aged slightly, output drift was less than 3 mv. in 45 minutes; this appeared to be due entirely to a gradual reduction of supply voltage from the batteries. Absolute accuracy, using published figures for sound velocity in water, was better than 5%.

No driver was available for adequate determination of overall frequency response; however, it would appear reasonable that at this sampling rate (5,000 measurements per second), frequency response would depend entirely on output filter characteristics. The low-pass R-C filter used has a corner frequency of 16 Hz, and should pass unimpeded biologic information, which may be assumed to have a

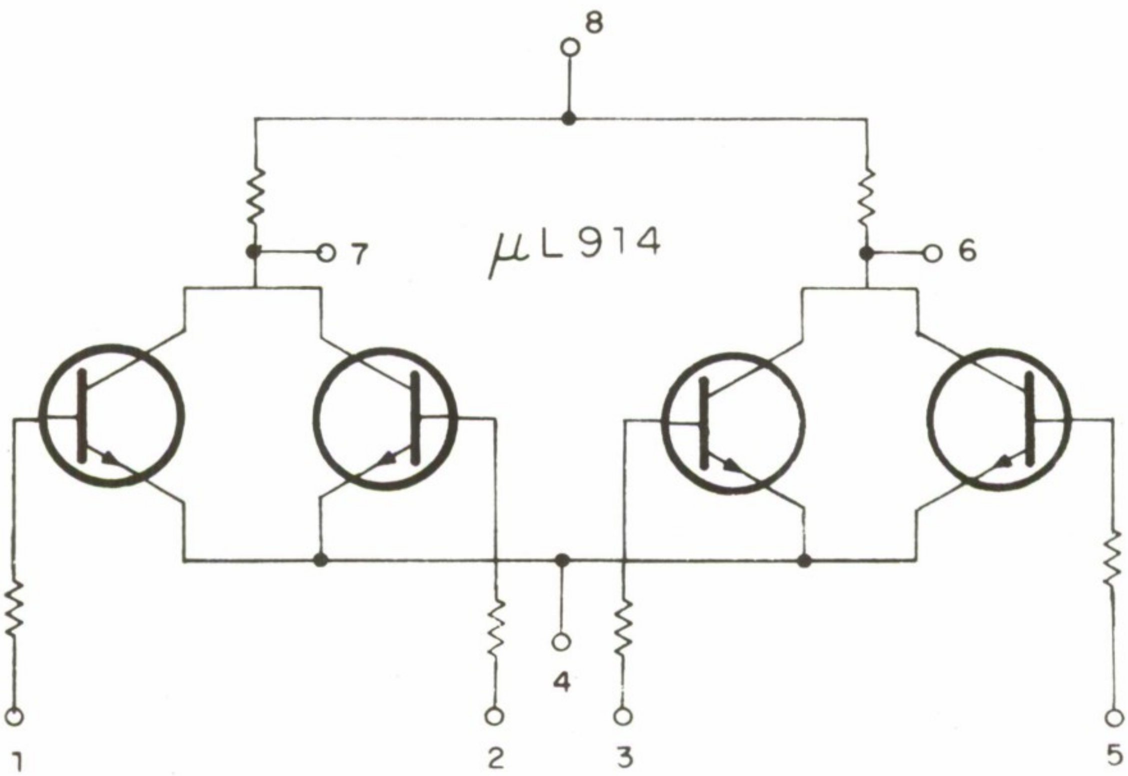

FIGURE 2C

Circuit diagram for Fairchild μL914.

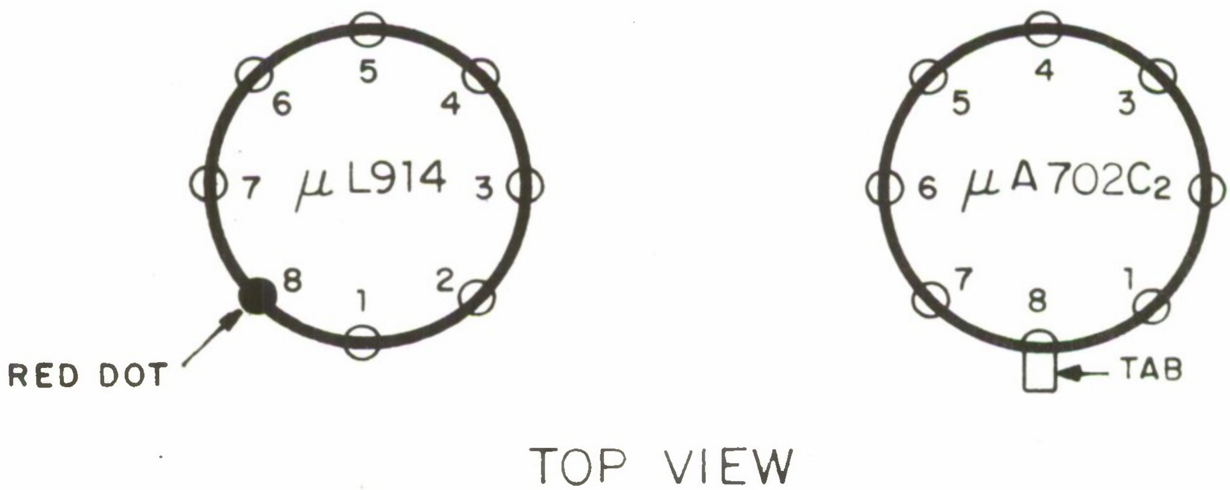

FIGURE 2D

Basing diagrams for μL914 and μA702C.

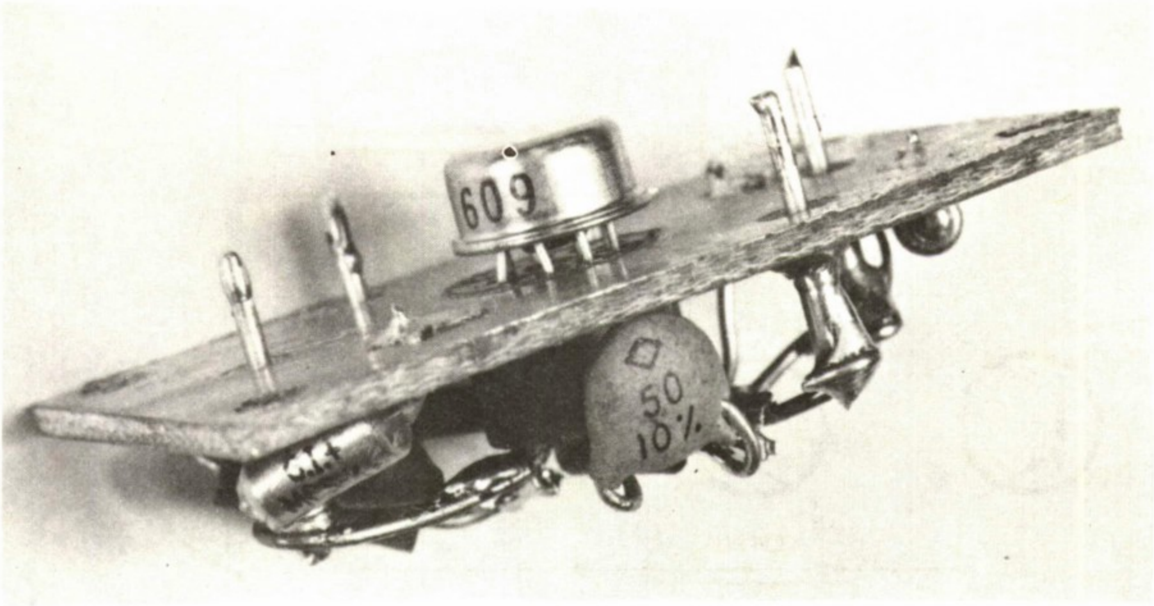

FIGURE 3

Each stage is built on a separate board. Connections are made from the integrated circuit socket to isolated pins. Copper coating used for ground is intact except around pins.

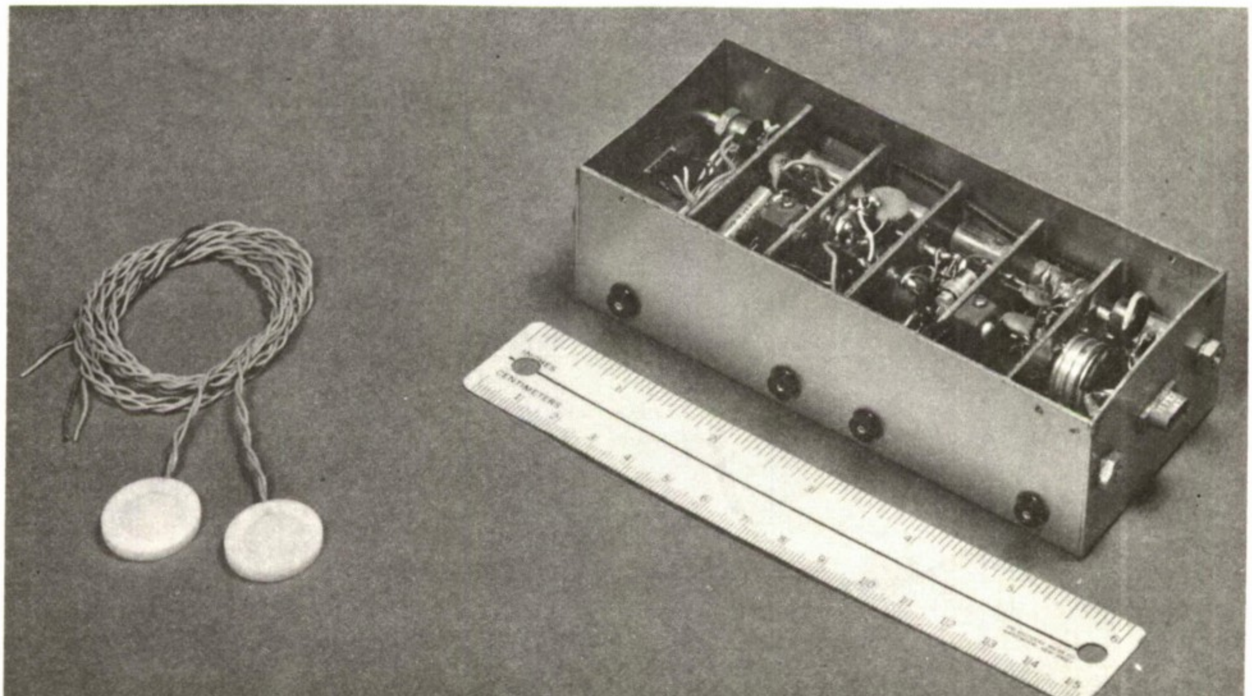

FIGURE 4

Completed sonomicrometer shows stacking of circuit cards using plastic separators. Pin jacks on lower edge of package are for test and signal monitoring purposes. One transducer pair is shown at left.

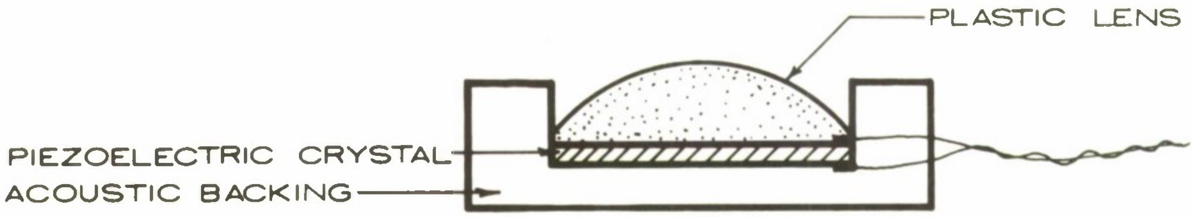

FIGURE 5

Transducer construction showing the crystal holder and diffusing lens. The holder, cast of polystyrene beads, also acts as acoustical backing.

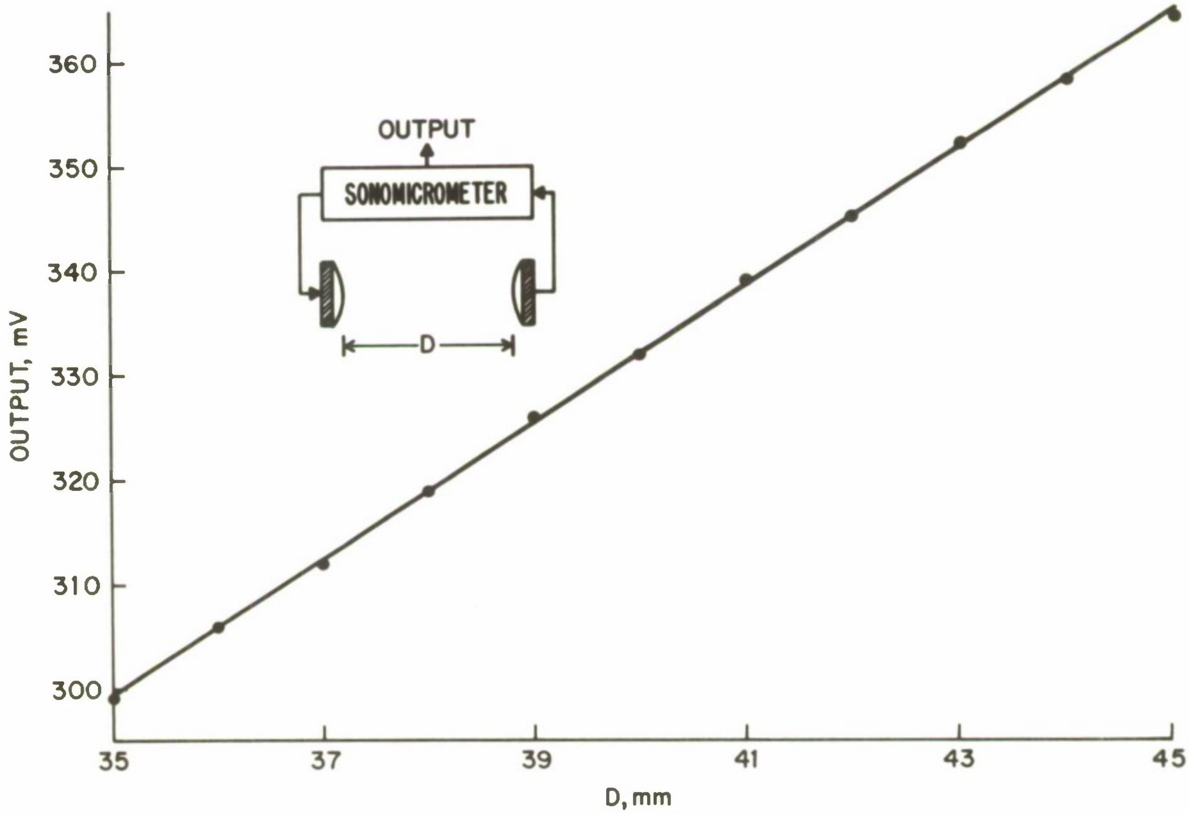

FIGURE 6

Sonomicrometer output as a function of crystal spacing; sensitivity is approximately 6.5 mv./mm. change in spacing.

maximum appreciable harmonic content of one-third this value. Phase shift may be assumed negligible by a similar argument.

Calibration

The velocity of ultrasound in biologic structures is approximately that for water at 37° C.—i.e., about 1.55×10^6 mm./sec. A calibration fixture was constructed of a rectangular ¼-inch Lucite sheet whose ends had been milled in steps (fig. 7). Crystals were glued to the Lucite faces, and transit time between each pair of crystals was measured accurately on an oscilloscope. Though the velocity of sound in Lucite is almost twice that

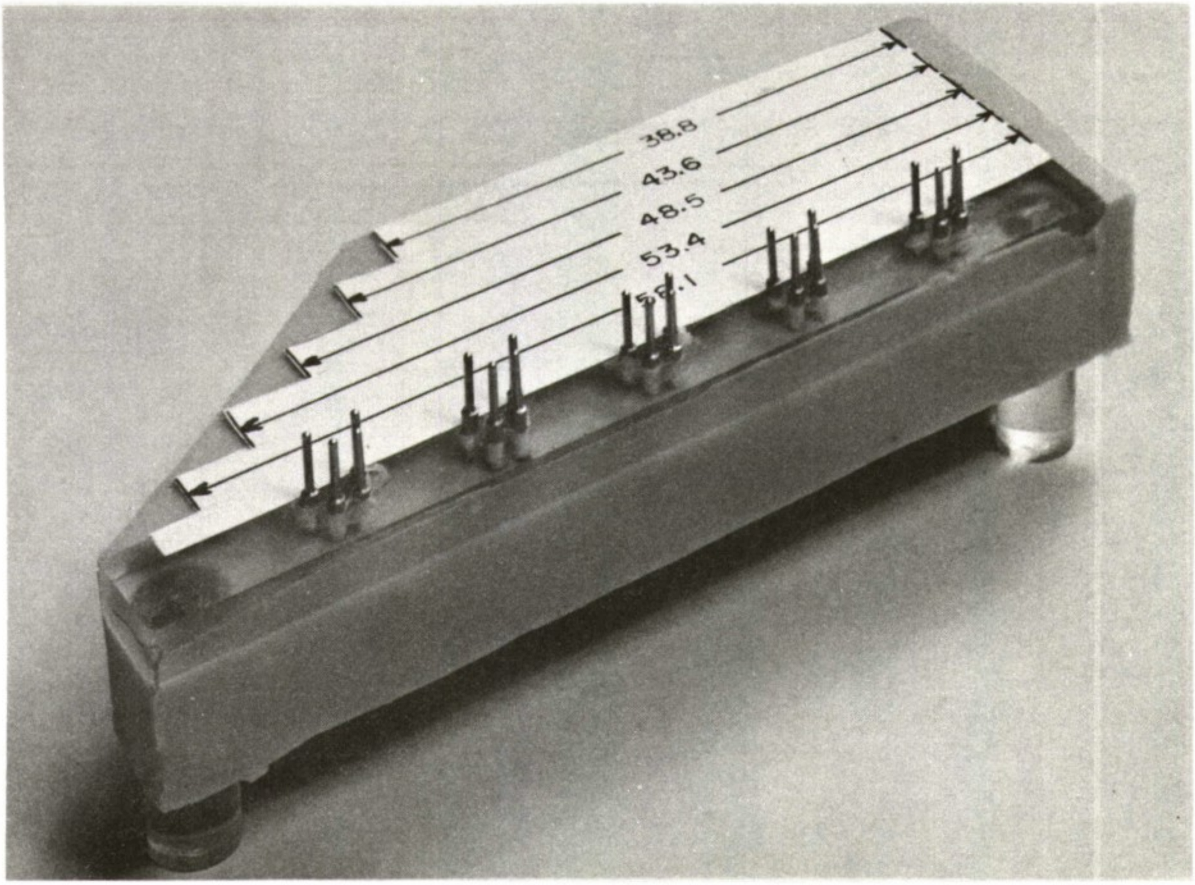

FIGURE 7

Calibration fixture with known water equivalent distances in millimeters. The fixture is made of Lucite and silicone rubber.

in water, a "water equivalent" was readily calculated and each crystal pair so labeled. During recordings from animal structures, these crystals with a known ultrasonic delay could be inserted at the instrument input and its output displayed on the recorder. Two such points were enough to calibrate each record. The calibrator was constructed to yield equivalent distances in water from 40 to 60 mm. in 5-mm. increments. This distance was sufficient to measure most of the canine hearts examined.

IV. DISCUSSION

Application

This instrument has been restricted thus far to making continuous measurements of left ventricular diameter in conscious dogs. Figure 8 shows records obtained from one dog at rest; pulmonary blood flow (by means of an electromagnetic flowmeter) and electrocardiogram were also recorded.

Crystal transducers were placed surgically across the left ventricle in healthy mongrel dogs. The heart was exposed through a left anterior oblique approach; the pericardium was incised; and the heart was lifted anteriorly while one crystal was sutured to the posterior surface of the left ventricle. The best position for the anterior crystal was determined by exploring the ventricular surface until the largest, most consistent ultrasonic burst was detected, and then the crystal was sutured into place. Both crystals were about 1 to 2 cm.

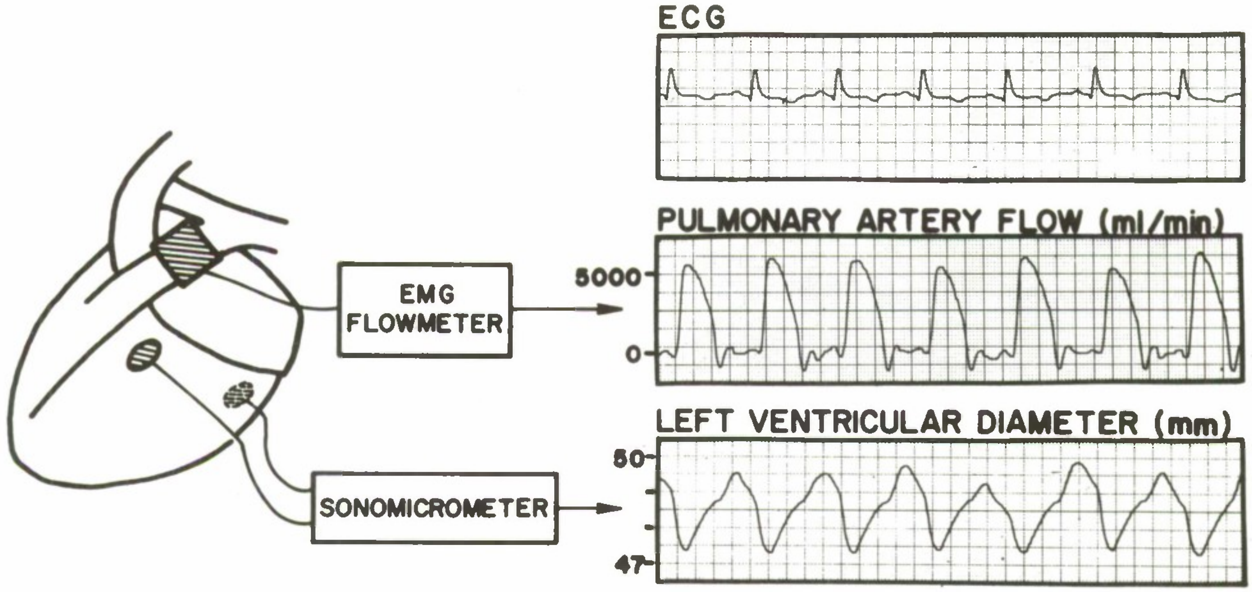

FIGURE 8

Simultaneous recordings of ECG, pulmonary artery flow (by means of an implanted electromagnetic flowmeter probe), and left ventricular diameter in a conscious dog. Paper speed, 25 mm./sec.

below the atrioventricular groove, and were directed across the greatest diameter of the left ventricle. Within the first day or two after surgery, the received signal appeared to reach its maximum. While some animals have thus far yielded usable records for several weeks following implantation, prediction of anticipated useful life cannot be made until more animals are studied. No adverse reaction to the transducers themselves has been seen.

Similar instruments have been used by others to measure dimensions across liver and spleen (4) or to estimate blood volume changes in a portion of mesentery (5). Crystals across a man's arm or leg have been used to measure diameter continuously, as a possible substitute for conventional plethysmography (6), and other possible applications are limited only by the imagination of the investigator.

Disadvantages

The measurement of a linear dimension is not by any means a substitute for measurement of an organ's volume although it may indirectly indicate changes in volume. Moreover, crystals applied to the outside of the dog heart measure thickness of both the myocardium and the contained blood. Usually the latter is the variable of interest.

Crystal design and application are not yet optimized. The leading edge of the received ultrasonic burst must rise out of the background noise fast enough to trigger reliably; this demands a reasonable degree of acoustical coupling between transmitting and receiving crystals, coupling which may be readily achieved on the operating table, but might gradually fade over the next few days as the size and shape of the dog heart return to normal. Other organs less affected by the surgical procedure itself should present fewer problems.

Some degree of skill in maintaining the instrument is still necessary. An oscilloscope with adequate frequency response (to 5 mHz) is essential. The waveforms at receiver, Schmitt, and bistable outputs should be checked repeatedly to assure that the triggering point

has not fluctuated. A multichannel oscilloscope is desirable when adjusting monostable delay and trigger points.

Future development

The device described here is sufficiently small to allow telemetered recordings from an animal roaming freely about the laboratory. This will be attempted when a more compact construction is complete. Further investigation of crystal transducer construction has already begun. Some other lens materials and designs have been examined. A careful study of ultrasonic dispersion by such technics seems indicated.

Other organs than the heart will be examined as well. Pulsations of kidney, liver, and mesenteric beds as perfusing pressure is altered can furnish valuable information about their function. Visceral motility in conscious animals could be easily studied by this technic.

REFERENCES

1. Rushmer, R. F. Cardiovascular dynamics. Philadelphia, Pa.: W. B. Saunders, 1961.

2. Peterson, L. H. General types of dimensional transducers. *In* Rushmer, R. F. (ed.). Methods of medical research, pp. 5-23. Chicago, Ill.: Year Book Medical Publishers, Inc. 1966.

3. Baker, D. W. Sonocardiometer. *In* Rushmer, R. F. (ed.). Methods of medical research, pp. 31-34. Chicago, Ill.: Year Book Medical Publishers, Inc., 1966.

4. Guntheroth, W. G., and G. L. Mullins. Liver and spleen as venous reservoirs. Amer. J. Physiol. 204:35 (1963).

5. Mullins, G. L., and W. G. Guntheroth. Continuous recording of changes in mesenteric blood volume. Ultrasonics 4:42 (1966).

6. Stegall, H. F., J. M. Ofstad, V. E. Simmons, and R. F. Rushmer. An integrated facility for peripheral vascular studies in man. (Abstract) Proc. 17th Ann. Conf. Eng. Med. Biol. 6:75 (1964).

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13. ABSTRACT

The design and construction of a relatively simple and inexpensive ultrasonic dimension gage (sonomicrometer) are described in detail. Two piezoelectric crystals are installed surgically across the organ to be studied, and the transit time for a burst of ultrasound to pass from one crystal to the other is measured. The device is easily calibrated when sound velocity in the medium is known. By use of integrated circuits throughout, it may be duplicated for less than $55. Possible applications other than continuous measurements of organ size are discussed.

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